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VACUUM PRECOOLING

A Comparison of the Cooling of Different Vegetables

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VACUUM PRECOOLING

A Comparison of Cooling of Different Vegetables

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SUMMARY

A comparison of several kinds of vegetables vacuum cooled under similar conditions showed striking differences in temperature reduction and weight losses.

The final temperatures obtained during 25- or 30-minute vacuum cycles with minimum pressures of 4.0 to 4.6 mm. Hg. ranged from 34° to 65° F., depending upon the rate at which the plant tissues lost moisture by evaporation. This moisture loss was high for lettuce leaves and green onions, resulting in final temperatures close to 34°. It was low for potatoes and zucchini squash, resulting in little cooling. Several other commercially important crops lost only enough moisture to be cooled to 40° to 45° under these conditions. Despite wide differences in the final temperatures obtained by vacuum, the amount of product cooling was proportional to the water loss. Temperature reductions agreed quite closely with the theoretical cooling of approximately 10 degrees F. for each 1 percent of moisture evaporated, regardless of the kind of crop.

The vacuum-cooling time also differed for different crops. After a certain time, further holding under vacuum at a constant pressure had little additional effect in reducing the temperature.

Pre-wetting supplied some or most of the water needed for evaporation to cool the commodity by vacuum, and consequently reduced the amount of moisture lost from within the plant tissue. Pre-wetting was beneficial for most crops, especially when the initial temperature was high and when the surface tissue retained an adequate amount of water after draining. Pre-wetting in excess of the theoretical amount needed to cool the commodity was of no benefit.

Most evaporation and cooling occurred soon after the "flash," but continued holding at low pressure was necessary to remove the heat from fleshy plant tissues. The "flash" occurs when the pressure level becomes low enough to start a substantial release of moisture from the commodity.

Evacuation to 4.0 mm. Hg. abs. was safe for these vegetables during vacuum cycles of 25 to 30 minutes. Lower pressures were not harmful in some instances, and apparently enhanced the degree of cooling.

Packaging materials retarded cooling by impeding the movement of moisture vapor away from the commodity when under vacuum, but reduced the rate of warmup after the vacuum was broken. Adequate ventilation of cartons or film wrappers was necessary to obtain desirable vacuum precooling of vegetables packed in shipping containers.

BACKGROUND

Since the start of commercial vacuum cooling of lettuce, research workers and shippers of fresh produce have been interested in using this method to precool other crops (3, 8, 9, 10, 11, 12).[1] Early investigation showed temperature reduction by vacuum varied greatly among different kinds of crops (2, 4).

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[1] Underscored numbers in parentheses refer to items in Literature Cited, p. 12.

Little information is available for a direct comparison of temperatures obtained by vacuum cooling different vegetables. In this study, several vegetables were vacuum cooled under similar conditions to determine the amount of cooling and moisture loss. The effects of cooling time, pre-wetting, and packaging on the final temperature of many of these commodities also were studied.

Vacuum cooling of fresh produce depends on the refrigeration resulting from the evaporation of water from the commodity. Theoretically, the evaporation of 1 pound of water from 100 pounds of fresh vegetables at vacuum-cooling pressures should cool the product about 10° F. if the evaporation is fast enough to offset the heat of respiration and heat absorbed from external sources during the cooling period (1).

This research is part of a broad program of the Agricultural Marketing Service for preserving high quality in fresh vegetables during marketing.

TEST PROCEDURE

Vacuum tank. --A pilot model vacuum tank with capacity of about 50 cubic feet, described previously (1), was used for these tests. The vacuum system, utilizing a mechanical pump for evacuating the tank and refrigerated coils for condensing the water vapor extracted from the commodity, was similar in type to many commercial installations. The same cooling conditions could have been produced with mechanical vacuum pumps and block ice condensers or steam-jet vacuum pumps and barometric condensers (5, 6, 7).

Data collected. --Tank pressures were measured as millimeters of mercury, absolute (mm. Hg., abs.), using a McLeod high-vacuum gage.

Temperatures were taken with 12 thermocouples connected to a recording potentiometer. They measured wet- and dry-bulb temperatures in the tank air, surface temperatures on the condenser coils, and commodity temperatures in leafy and fleshy tissue. Final temperatures of the commodities were taken by reinserting the thermocouples into tissue not previously punctured (1).

Where applicable, temperatures of leafy and fleshy (butt) portions of the commodity were averaged for "pulp" or product temperatures. No attempt was made to determine the proportion of leafy and fleshy tissue involved. Moisture loss was determined by weighing the commodity before and after vacuum cooling.

Most tests were run with small lots of vegetables held loosely in open containers.

Operation of the vacuum tank. --During the vacuum cycle, the pressure in the tank was dropped from an initial 760 mm. (atmospheric) to 50 mm. Hg. in the first 3 or 4 minutes and from 50 mm. to 5.0 mm. Hg. in the next 3 or 4 minutes. The minimum pressures desired were usually obtained soon thereafter and were held for the remainder of the vacuum cycle by bleeding air into the tank when necessary. In most tests, the tank pressure was not allowed to drop below 4.0 mm. Hg. At the end of the vacuum cycle, about 2 minutes were allowed for the tank to regain atmospheric pressure. The curve shown as "boiling temperature of water at tank pressure" in figure 1 was typical of the evacuation in most tests.

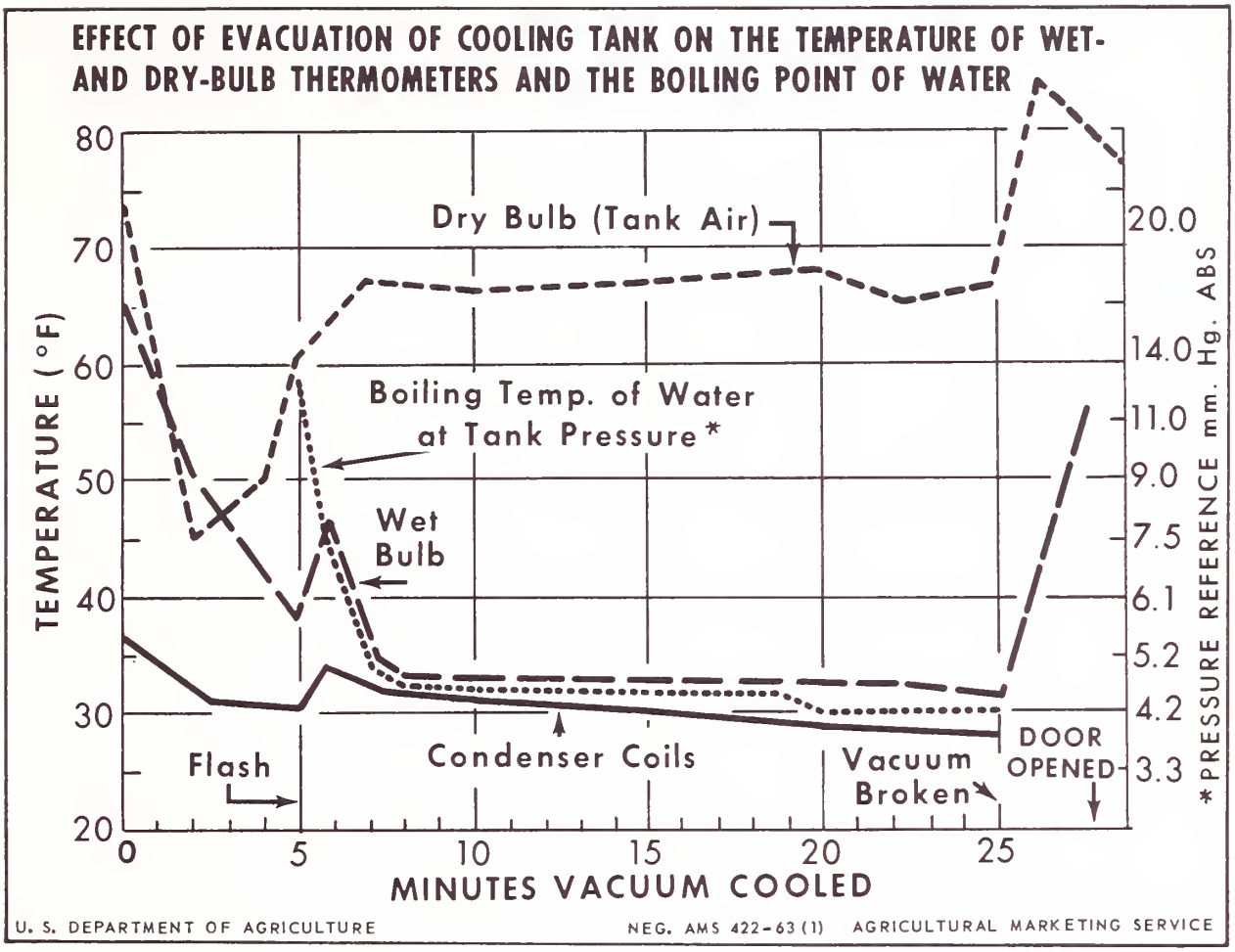

Figure 1

RESULTS AND DISCUSSION

Effect of evacuation on the temperature of wet- and dry-bulb thermometers.--During a typical vacuum cycle, the temperatures of the wet - and the dry-bulb thermometers suspended in the tank dropped rapidly as the air was exhausted (fig. 1). When the pressure became low enough to pull moisture from the commodity, both wet - and dry-bulb temperatures rose sharply because of the heat of vaporization. From this point on, the dry-bulb reading or "air" temperature changed very little, but the wet bulb cooled rapidly as the tank pressure was lowered.

The sudden rise in the temperature, or "flash," of the wet bulb early in the vacuum cycle indicated the start of cooling in the commodity. After the flash, the temperature of the wet bulb nearly coincided with the boiling point of water at the tank pressure (fig. 1). When the pressure in the tank reached 4.6 mm. Hg. (the point at which water boils at 32° F.), the wet-bulb wick froze and, thereafter, the bulb temperature did not respond readily to downward changes in tank pressure.

At the end of the run, the rise in wet- and dry-bulb temperatures reflected the heat of compression in the tank as the atmosphere was brought back to normal pressure.

During the vacuum cycle, the wet-bulb temperature was a good indicator of the tank pressure and of the resultant evaporative cooling potential from the start of commodity cooling (flash) until the pressure became low enough to freeze the wick. Thereafter, precise control of tank pressure required reference to the high-vacuum gage. The dry-bulb thermometer was of no value as an indicator of product cooling or tank pressure.

Effect of initial product temperature. --Different initial temperatures had little effect on final temperatures of a particular commodity when various lots were vacuum cooled at the same time. Warm sweet corn started to cool sooner than cooler corn, but both lots reached about the same temperature in a short time and continued to cool at the same rate thereafter (fig. 2). Similar results were obtained with the other crops tested. The major effect of initial temperature was the amount of product moisture lost during vacuum cooling--the higher the initial temperature, the greater the loss ("dry" lots, table 1).

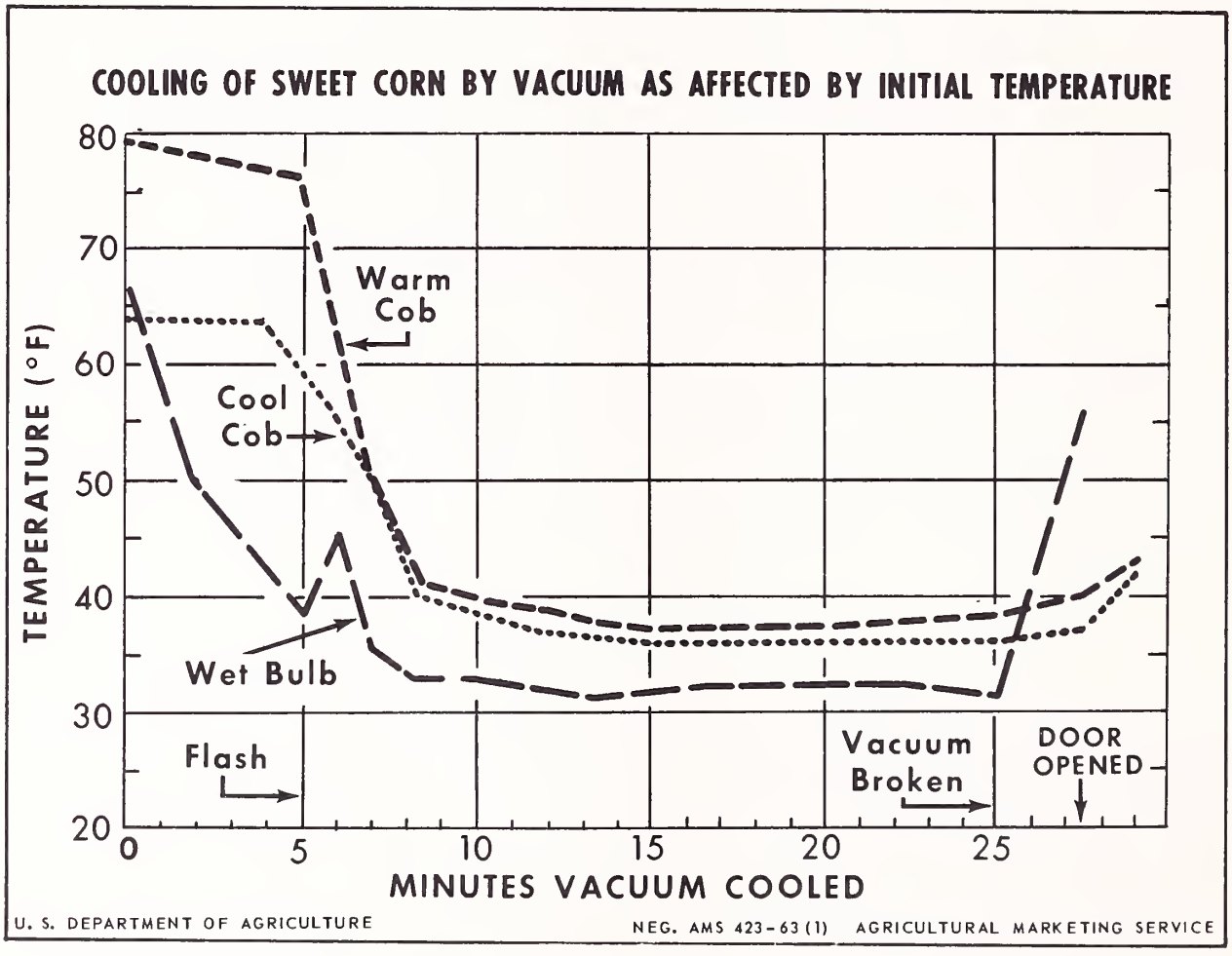

Figure 2

TABLE 1.--Effect of time on cooling and weight loss in vacuum-cooled vegetables[1]

Commodity	Vacuum cycle	Temperature			Weight loss
		Inital	Final	Reduction	
	Minutes	°F	°F	°F	Pct.
Asparagus	20	67	50	17	1.5
	30	69	47	22	2.3
Brussels sprouts	13	64	41	23	2.3
	20	63	40	23	2.5
	25	62	40	22	2.4
Cauliflower	22	63	53	10	1.5
	30	69	49	20	2.1
	40	68	45	23	2.4
Celery	20	63	50	13	1.3
	30	62	46	16	1.5
	40	63	47	16	1.6
Corn	11	66	49	17	1.8
	17	67	44	23	2.4
	20	69	43	26	2.8
	29	67	41	26	2.7
Lettuce	10	67	44	23	2.6
	15	66	43	23	2.9
	20	68	42	26	3.0
	25	71	38	33	3.5
	30	72	35	37	4.2
Peas	22	70	52	18	1.8
	25	71	47	24	2.4
	33	70	37	33	3.4

[1] Vacuum-cooling conditions: Minimum pressures, 4.0 to 4.6 mm. Hg.; condenser temperatures, 29° to 32° F; "flash" at approximately 5 minutes.

Crop differences.--On the average, various crops differed greatly in the final temperature obtained by vacuum cooling (fig. 3). When evacuated to minimum pressures of 4.0 to 4.6 mm. Hg., lettuce, green onions, and carrot tops with initial temperatures ranging from 68° to 72° F. were cooled to about 35° F. in 25 to 30 minutes. Under similar treatment, artichokes, asparagus, broccoli, Brussels sprouts, cabbage, celery, corn, and peas were cooled only to 40° to 45°. Temperature reduction was still less in cauliflower and snap beans, and very little cooling occurred in carrot roots, potatoes, and zucchini squash. In other tests, parsley and a salad mix of shredded cabbage and carrots prepackaged in perforated film bags were cooled to temperatures below 40° F. with no difficulty (table 3).

TABLE 2.--Effect of pre-wetting on final temperatures and weight loss in vacuum-cooled vegetables[1]

Commodity	Vacuum-cooled "dry"			Vacuum-cooled "wet"				
	Temperature		Weight loss	Temperature		Water added[2]	Weight loss[3]	Net change in weight[4]
	Initial	Final		Initial	Final			
	°F	°F	Pct.	°F	°F	Pct.	Pct.	Pct.
Artichokes (Globe)	89	45	4.7	82	43	1.6	4.3	-2.7
	72	43	3.3	70	45	2.9	3.4	-0.5
	67	45	2.5	65	44	3.8	3.4	+0.4
Asparagus	80	47	3.6	80	42	2.0	4.0	-2.0
	70	43	3.0	70	40	3.0	3.0	0
	64	46	1.7	64	44	2.0	2.0	0
Broccoli	63	42	2.2	64	44	3.1	2.5	+0.6
Brussels sprouts	77	38	3.7	72	38	3.0	3.4	-0.4
	65	40	2.6	65	38	3.2	2.6	+0.6
Carrot roots	70	56	1.5	72	57	1.0	2.0	-1.0
Cauliflower	69	47	2.8	70	43	3.1	3.5	-0.4
	59	46	1.5	60	40	3.5	3.2	+0.3
Celery	71	47	2.4	71	44	4.3	3.3	+1.0
	63	50	1.5	64	47	2.4	2.0	+0.4
Corn	86	45	4.3	81	41	5.4	5.2	+0.2
	68	46	3.0	70	41	3.0	3.6	-0.6
	57	42	1.5	55	41	2.7	1.7	+1.0
Lettuce	79	35	4.6	85	34	6.7	5.6	+1.1
	64	38	3.2	66	35	6.1	3.8	+2.3
	53	34	2.3	51	34	7.7	3.1	+4.6
Onions (green)	70	35	3.8	68	35	9.0	4.3	+4.7
Peas	79	40	4.5	81	41	3.0	4.0	-1.0
	65	41	3.0	67	40	4.4	3.0	+1.4
Snap beans	70	55	1.4	68	51	2.5	3.0	+0.5
Zucchini squash	67	60	1.1	65	60	1.2	.6	+0.6

[1] Vacuum conditions: Minimum pressures 4.0 to 4.6 mm. Hg.; condenser coils 29° to 32° F; time in tank 25 or 30 minutes.
[2] Percent of initial product weight.
[3] Percent of initial "wet" weight.
[4] Net gain or loss based on weight before wetting.

In these tests, with initial product temperatures around 70° F., moisture losses during vacuum cooling averaged 1 percent or less in potatoes and zucchini squash and around 4 percent in lettuce, onions, and carrot tops. The greatest temperature reductions occurred in the crops that lost moisture most readily.

Two factors related to moisture loss largely control the adaptability of a particular product to vacuum cooling. The first is the ratio of surface area to total mass. Lettuce, with its vast leaf area for evaporation, is readily cooled, whereas snap beans, with limited surface area, are less well adapted to such cooling (4). The second factor is the permeability of the surface layer to water vapor. Potatoes and tomatoes have impermeable skins in addition to proportionally small surface areas and, as would be expected, do not cool well under vacuum (2, 4). When the vapor barrier was removed from potatoes by peeling, more cooling was obtained relative to the total mass of plant tissue (fig. 3).

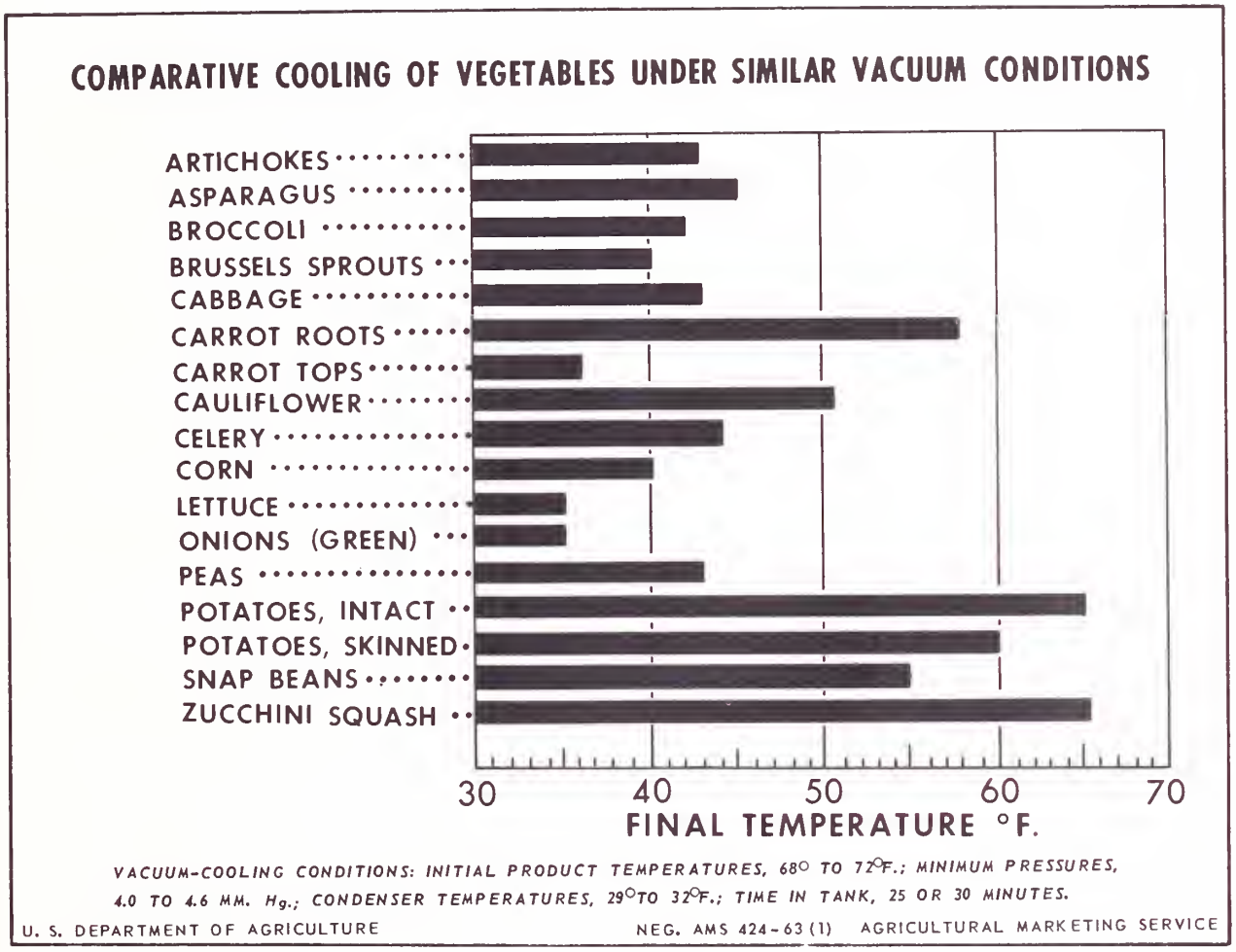

Figure 3

Ratio of cooling to weight loss. --Despite the differences in final temperatures, cooling in all crops was proportional to the amount of moisture evaporated from the commodity during the vacuum cycle. Temperature reductions averaged 9 to 10 degrees F. for each 1 percent of initial weight lost, regardless of the kind of crop (fig. 4).

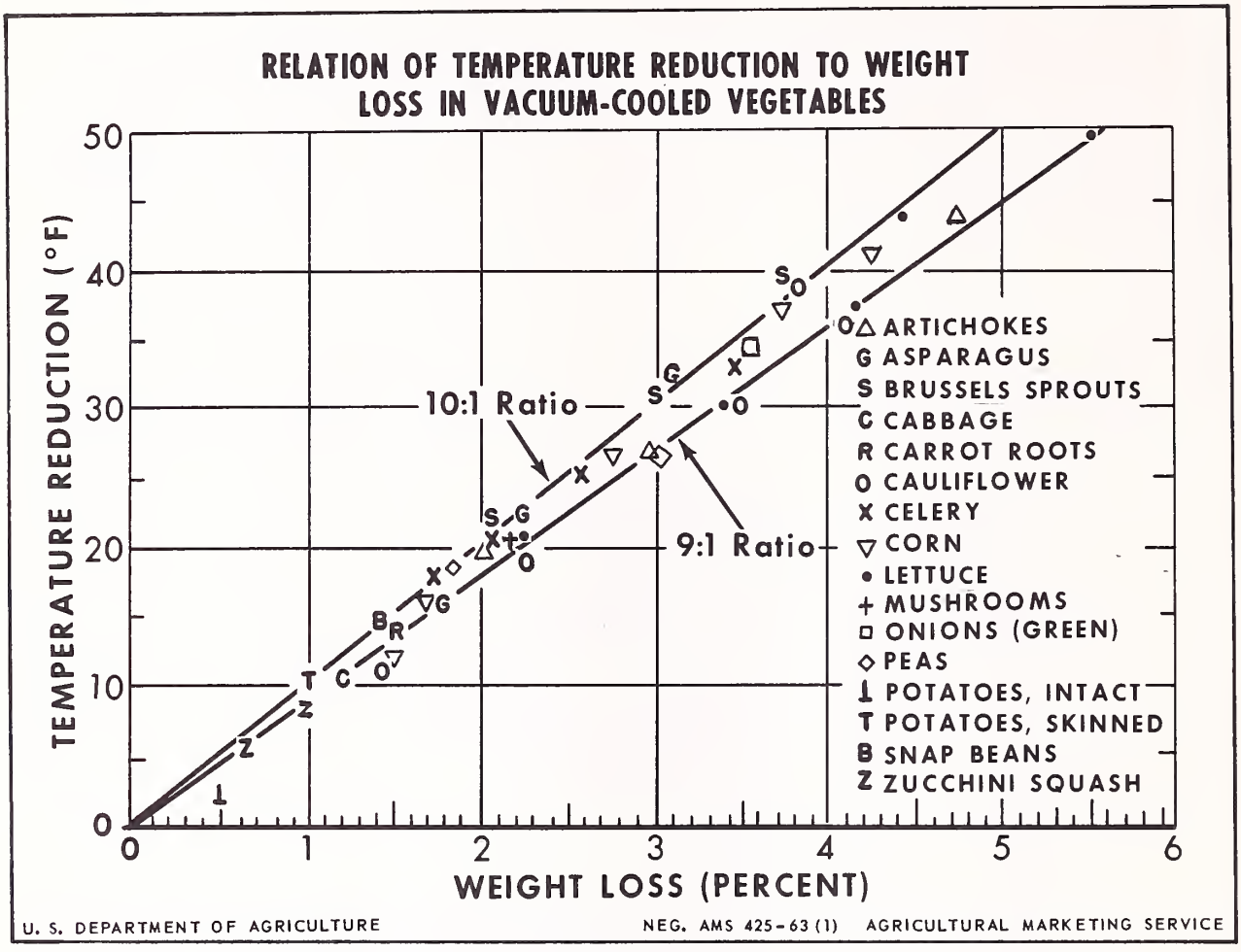

Figure 4

Time required for cooling. --The time required for vacuum cooling varied with the kind of crop (table 1, p. 7). When evacuated to 4.0 to 4.6 mm. Hg., Brussels sprouts and sweet corn were cooled nearly to their full potential for this pressure range in 13- and 17-minute vacuum cycles, respectively. Additional time had little effect in further temperature reduction or weight loss. The cooling of asparagus, celery, lettuce, and peas was improved by extending the vacuum cycle to about 30 minutes. Lettuce leaves cooled rapidly, but additional time was required to remove the heat from the butt portion of the head. Cauliflower was cooled to about 50° in 30 minutes and required 40 minutes for cooling to 45° F. with these tank pressures.

Pre-wetting. --Pre-wetting is recommended for vacuum cooling of some crops (9, 11, 12). Since cooling by vacuum is dependent entirely upon the amount of moisture evaporated, supplemental water applied to the surface should reduce the amount lost from the plant tissue and possibly promote additional cooling.

The amount of water absorbed by or adhering to the vegetables after wetting ranged from about 1 percent of the initial weight, in carrot roots and zucchini squash, to as much as 8 to 9 percent in lettuce and bunched green onions (table 2).

Single heads of celery and lettuce, bunches of green onions, and baskets of peas retained more water after pre-wetting and draining than was needed for cooling by evaporation, and consequently showed net gains in weight after evacuation. Most other crops did not retain enough water, after pre-wetting, for complete cooling and therefore lost moisture from the plant tissue. The loss in original weight during vacuum cooling was always less in pre-wetted lots than in lots cooled without wetting. Pre-wetting was most beneficial when the initial product temperature was high and the amount of water held on the surface after draining was sufficient for the cooling requirement. Water in excess of this amount was not evaporated and remained on the product after cooling was completed.

Effect of packaging. --Vacuum cooling of some vegetables was retarded by packaging. Brussels sprouts, trimmed cauliflower, and celery hearts did not cool quite as well when packaged in film wraps or film-covered cups as they did in open-mesh baskets (table 3). Conversely, corn, lettuce, and parsley were cooled as well in the listed packages as when exposed. Also, these packaged crops warmed up slower than exposed lots when the vacuum was broken.

TABLE 3.--Effect of packaging or condition on cooling and weight loss in vacuum-cooled vegetables[1]

Commodity and condition	Packaging material	Temperature			Weight loss
		Initial	Final[2]		
		°F.	"A"	"B"	Pct.
Brussels sprouts	None	66	38	40	2.6
	Wax cup, lumarith top	68	40	42	2.4
Cabbage	None	71	41	44	3.0
	Carton	71	42	42	3.1
Cauliflower	None	63	46	50	1.7
	Perforated film, single heads	63	48	53	1.5
Celery, hearts	None	65	44	47	1.9
	Perforated film bag	66	44	48	1.8
Celery, whole heads	Crate, 2-1/2 doz.	62	43	45	1.7
	Carton, 1 doz.	67	45	47	1.4
Corn	None	76	36	40	3.8
	Carton	76	35	38	3.6
Lettuce	None	67	36	38	3.7
	Carton	66	35	36	3.3
Parsley	None	78	35	42	4.9
	Perforated film bag	78	35	37	4.1
Potatoes, intact	None	68	64	65	0.5
Potatoes, skinned	None	70	58	60	1.0
Salad mix	Perforated film bag	62	35	35	3.0
	Nonperforated film bag	62	--	55	0.8

[1] Vacuum-cooling conditions: Minimum pressures, 4.0 to 4.6 mm. Hg.; condenser temperatures, 29° to 32° F; "flash" at approximately 5 minutes; time in tank, 25 or 30 minutes.
[2] "A", minimum temperature recorded during vacuum cycle; "B", temperature of uninjured tissue taken after vacuum was broken.

Ventilation in containers and package films was also a factor in vacuum cooling. Cooling was more rapid in celery packed in wooden crates than in less ventilated cartons (table 3). A salad mix of shredded cabbage and carrots was cooled very little when packaged in nonventilated film bags, but the temperature dropped readily to 35° F. in perforated bags.

Adequate, but not excessive, ventilation of containers and package films was desirable for most effective vacuum precooling and subsequent holding of vegetables packaged for shipment.

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